Memorandum

Date: June 16, 2003

To: Tara Smith, Chief
Delta Modeling Section

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Delta Modeling Section
From: **Department of Water Resources**

Subject: Delta Modeling Results in Proof of Concept of Forecasting California Aqueduct Water Quality

DSM2 simulations of 1998 Delta conditions, using the Division of Operation and Maintenance's monthly forecasted hydrology and operations, have been completed in order to provide data for Municipal Water Quality Investigation's proof of concept of forecasting water quality in the California Aqueduct. This memo presents the assumptions, methodology, and results of these simulations.

Background

The goal of MWQI's Real Time Data and Forecasting Project is to integrate real-time water quality data with computer models in order to provide water quality forecasts of Delta exports. One of the RTDF work plan elements under the most recent draft Implementation Plan (May 29, 2003) is forecasting tools. This element includes the task of completing a proof of concept for generating water quality forecasts at several locations along the California Aqueduct. Under this task, O&M's monthly forecasted hydrology and operations are to be used by DSM2 to simulate corresponding Delta conditions, including water quality at State Water Project and Delta-Mendota Canal export locations. This data will, in turn, be used as input to Metropolitan Water District's California Aqueduct Model in order to simulate water quality along the canal.

As part of the proof of concept, Delta conditions associated with several forecasts were to be simulated from a single year, along with simulated historical conditions. Due to data availability for the DSM2 simulation, calendar year 1998 was chosen for this study. In addition, the 50% exceedance forecasts from January, March, and May were chosen in order to explore the usefulness of simulating Delta conditions for forecasts early in the year. Water quality was to be provided in electrical conductivity (EC), total dissolved solids (TDS), and bromide at the DMC and SWP export locations.

General Delta Modeling Assumptions

The simulation of historical conditions from 1998 used the historical boundary tide, Delta inflows, Delta exports, and boundary EC. Delta island diversions and agricultural drainage was generated by the Delta Island Consumptive Use model (DICU), a land use-based estimation of island agricultural water use and drainage. Drainage water quality was based upon published average values that are assigned to one of three regions in the Delta and varies monthly. The operation of the Delta Cross Channel, Clifton Court Forebay Intake Gates, and the installation and operation of the south Delta temporary barriers were all taken from records for the historical simulation.

The three forecasts were simulated using forecasted monthly average Delta inflows and exports from DWR O&M's monthly-forecasted hydrology. The boundary tide during a forecast period was the forecasted astronomically-adjusted tide that is commonly used in extended planning studies by the Delta Modeling Section (see below). Boundary EC was derived for forecasts from relationships between flow and EC. At the downstream boundary Martinez, EC was determined by the artificial neural network used in planning that relates Martinez EC to Delta outflow. Daily average EC at Martinez is then used to assign hourly EC values based upon tidal-EC relationships here. Net Delta consumptive use was included in O&M's monthly forecasts and was used to distribute agricultural diversions and drainage via the Adjusted Delta Island Consumptive Use Model (ADICU). The operation of Delta structures for the January, March, and May forecasts was either given in the O&M forecast, or assumed in a manner consistent with current planning studies (see below).

Daily changing historical conditions were simulated up to the start of each forecast, at which time the forecast, based upon monthly averaged Delta inflows, exports, and forecasted boundary tide, began. Initial Delta conditions at the start of any forecast, then, reflect the Delta conditions as modeled up to that moment in the historical simulation.

Delta Hydrodynamic Simulations

Downstream Tide at Martinez

All forecasts used the forecasted astronomically-adjusted tide at Martinez from the day of the start of the forecast (January 1st, March 1st, or May 1st). This tide, currently used in Delta Modeling Section planning studies, is based on the forecasted astronomical tide at Martinez and captures the repeating spring-neap sequence. However, as shown in Figure 1, this predicted tide can vary significantly from the historical tide at Martinez and hence contribute to forecasted hydrodynamics deviating from historical.

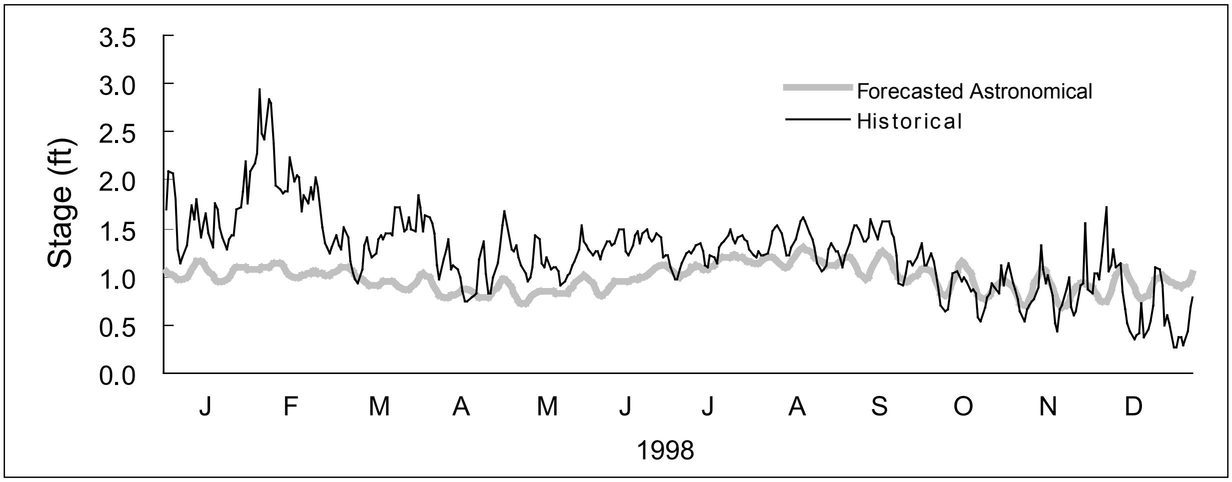

Figure 1. Daily average historical and forecasted astronomical tide at Martinez.

Boundary Inflows

The historical and forecasted combined Sacramento River and Yolo Bypass inflows and the San Joaquin River inflows are shown in Figures 2 and 3, and summarized in Table 1. Most notable is the failure of the January 1st forecast for 1998 to account for the high historical Delta inflows in January and February; however, all forecasts seriously underestimated Sacramento River inflows in June and December and San Joaquin River inflows in June and July. The May 1st forecast was marginally better than the January 1st and March 1st forecasts from May onward.

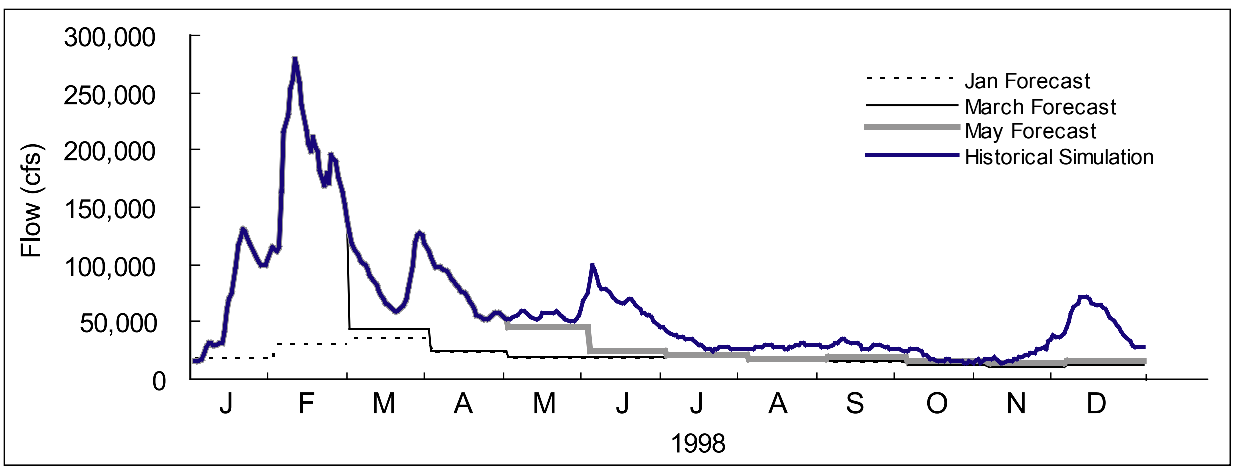

Figure 2. Historical and forecasted Sacramento River and Yolo Bypass inflow for 1998.

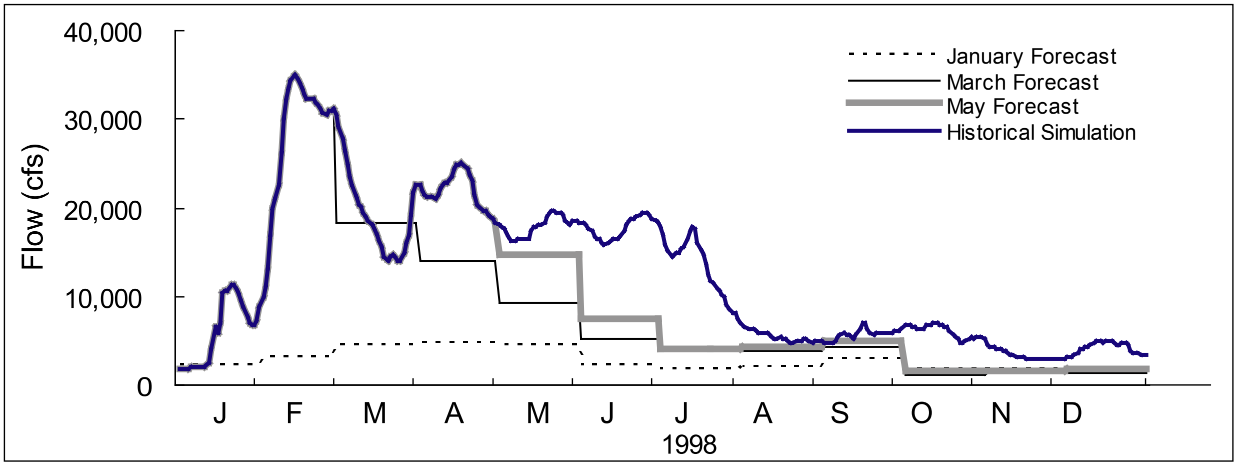

Figure 3. Historical and forecasted San Joaquin River inflow for 1998.

Delta Exports

Historical and forecasted 1998 SWP and DMC exports are shown in Figures 4 and 5, and summarized in Table 1. The January and March forecasts failed to predict the winter and spring decreases in exports due to missing the general wet conditions experienced in 1998. The three forecasts were generally similar during the summer and early fall months.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sacramento River													
Historical Simulation		74,826	198,004	91,026	72,985	56,268	67,146	30,615	28,402	28,952	18,076	23,684	51,379
Forecast	January	16,898	29,642	34,885	23,309	16,833	17,192	20,899	18,296	14,419	12,474	12,251	14,100
	March	74,826	198,004	43,017	24,832	18,733	18,431	21,600	19,160	15,280	11,921	11,243	12,751
	May	74,826	198,004	91,026	72,985	45,217	25,118	20,812	18,291	19,123	16,377	13,646	15,092
San Joaquin River													
Historical Simulation		6,012	28,091	19,360	21,942	17,948	17,760	13,209	5,445	5,756	6,041	3,370	4,187
Forecast	January	2,228	3,268	4,586	4,655	4,407	2,370	1,822	2,098	2,891	1,789	1,882	1,870
	March	6,012	28,091	18,215	14,016	9,205	5,143	4,066	3,871	4,252	1,138	1,344	1,464
	May	6,012	28,091	19,360	21,942	14,637	7,462	4,180	4,359	4,924	1,545	1,597	1,708
SWP Pumping													
Historical Simulation		3,197	131	233	31	703	2,167	3,471	4,297	4,474	4,795	2,176	2,082
Forecast	January	4,570	2,799	3,253	3,092	2,041	1,647	6,196	6,440	6,453	4,505	5,378	6,375
	March	4,570	2,799	960	3,092	2,041	1,647	6,196	6,440	6,453	4,017	3,596	4,716
	May	3,188	87	228	39	504	3,832	6,408	6,343	6,487	6,408	3,697	2,326
CVP Pumping													
Historical Simulation		3,952	2,956	2,062	1,446	2,320	2,862	4,060	4,371	4,357	4,162	2,136	33
Forecast	January	4,228	4,085	4,228	3,412	2,765	4,033	4,489	4,489	4,403	4,228	4,033	4,033
	March	4,228	4,085	4,228	3,412	2,765	4,033	4,489	4,489	4,403	4,228	4,033	4,033
	May	3,952	2,851	2,049	1,445	2,895	4,369	4,472	4,554	4,403	4,228	4,201	4,228

Table 1. Monthly average historical and forecasted Delta inflows and exports for 1998 (all values in cfs).

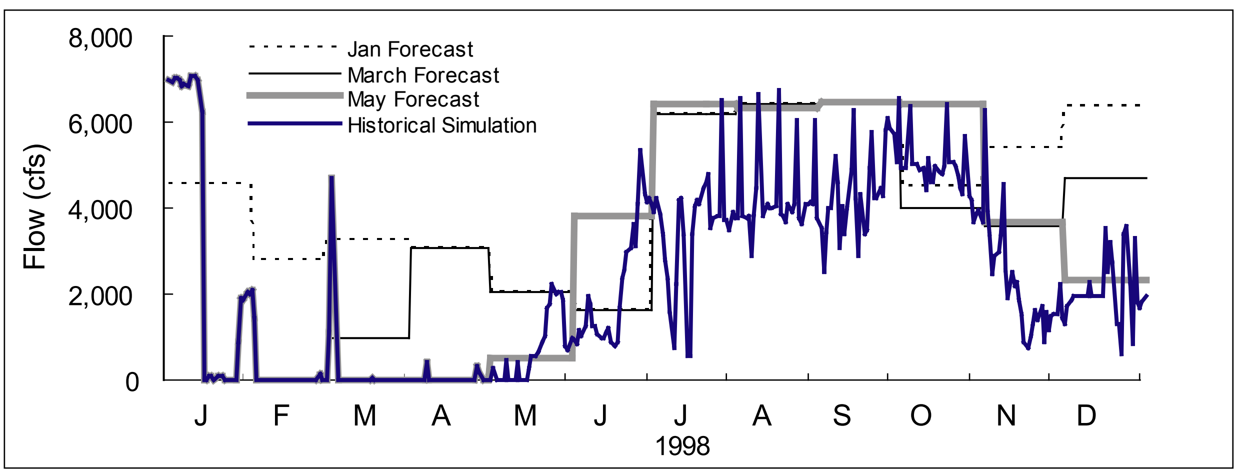

Figure 4. Historical and forecasted SWP exports for 1998.

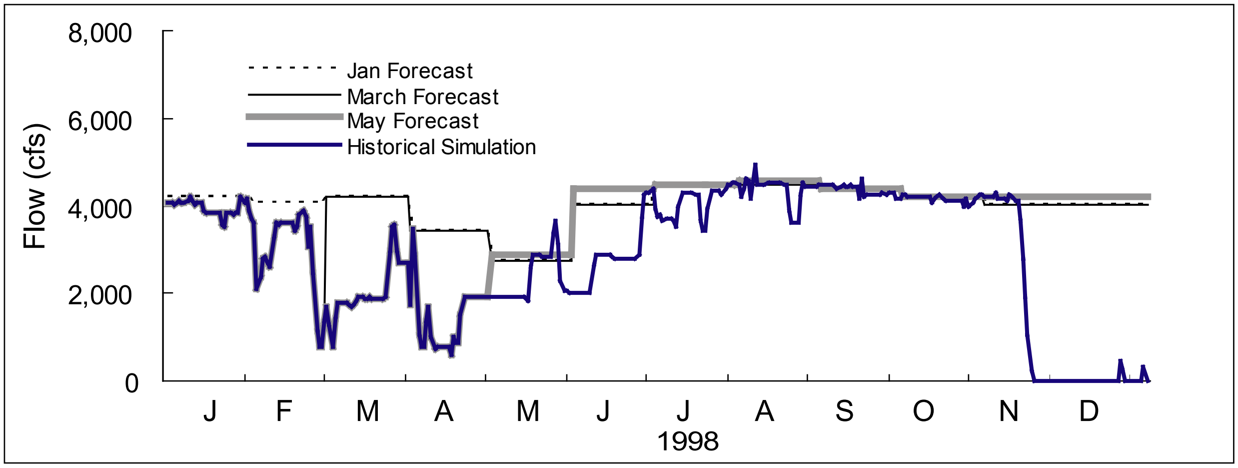

Figure 5. Historical and forecasted DMC exports for 1998.

Operation of Delta Structures

The Delta Cross Channel operation is included in the Delta forecasts in terms of the percentage of time open each month. This operation is determined by Delta standards and the flow in the Sacramento River. Figure 6 shows the historical and forecasted Sacramento River flow and the Delta Cross Channel operation. The Delta Cross Channel was opened during the same periods for each of the forecasts, but this timing deviated from the historical operation, potentially affecting internal Delta circulation patterns and salinity movement.

The installation and operation of the temporary agricultural barriers in Old River, Middle River and Grant Line Canal and the fish barrier at the head of Old River are dependent upon the time of year and the flow in the San Joaquin River (Table 2). As shown in Table 3, the historical high flows in the San Joaquin River in 1998 either prevented or made the installation of the temporary barriers unnecessary. Therefore, no barriers were historically installed and operated in the south Delta in 1998. However, all three forecasts projected San Joaquin River flows low enough to suggest nearly normal installation and operation, per the assumptions as specified in Tables 2 and 3. The three forecasts projected similar agricultural barriers use, but the January 1st forecast called for the installation of the head of Old River barrier in the spring while the March 1st and May 1st forecasts did not. These differences in south Delta barriers installation may, at times, cause significant differences in flow patterns in the south Delta between the historical and forecasted runs, and between the January 1st forecast and the March1st and May 1st forecasts in the April 15 – May 15 period.

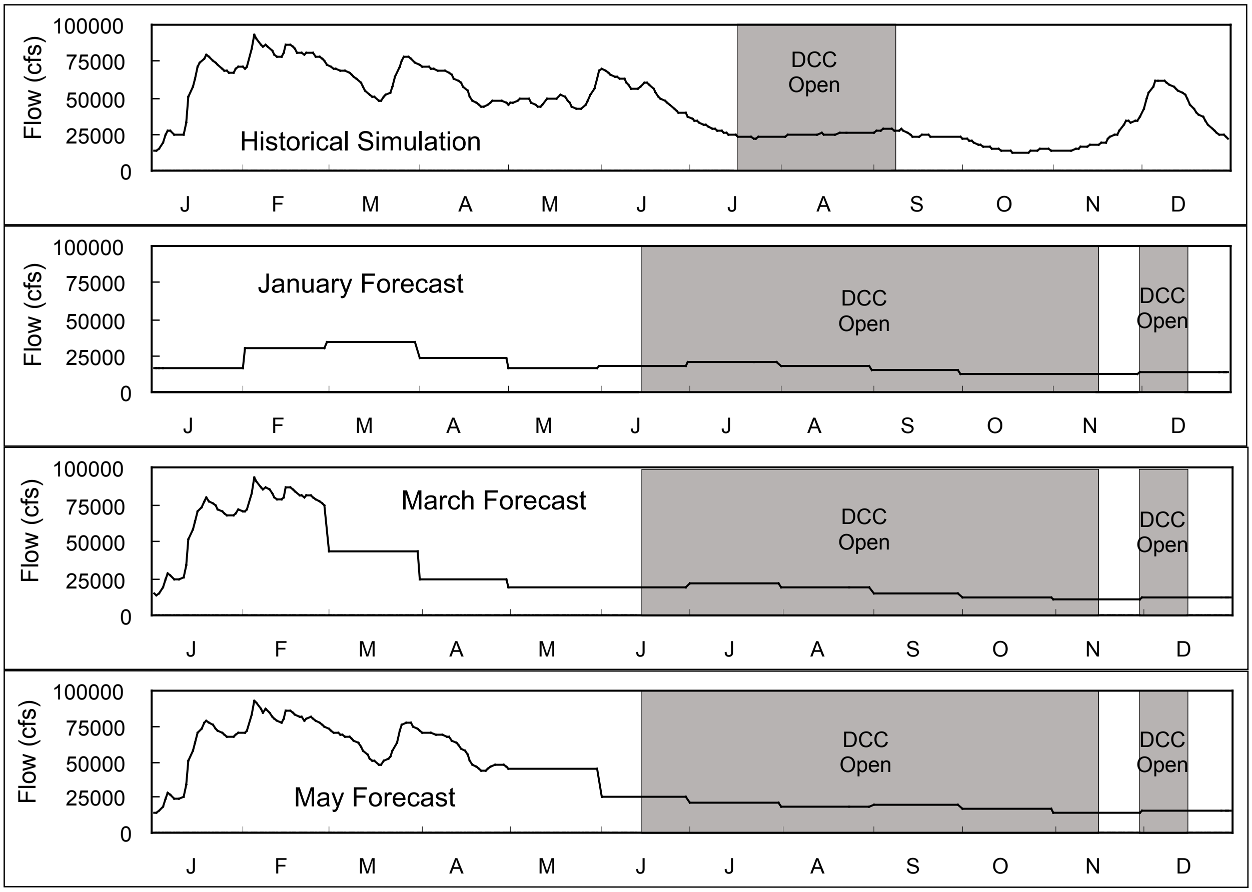

Figure 6. Historical and forecasted Sacramento River inflow and Delta Cross Channel operation for 1998.

Old River at Head

Not installed until Vernalis flow is below 5,000 cfs
Removed any time Vernalis flow exceeds 8,500 cfs

Agriculture Barriers

Not first installed until Vernalis flow falls below 12,000 cfs
Removed if Vernalis flow exceeds 18,200 cfs to protect against flooding
20' notch cut into weir for Sept 16 - Nov 30 period
During Apr 16 - May 15 period:
- Only boat ramp and culverts installed at Grant Line Canal site
- No barriers installed if ORH not installed due to high Vernalis flows
- If ORH barrier first installed then removed due to high Vernalis flows, MR and ORT culverts tied open

Table 2. Installation and operational criteria for temporary barriers in forecast.

Water Quality Simulation

DSM2 water quality simulations were in EC with values at the DMC and SWP intakes converted to total dissolved solids (TDS) and bromide through relationships derived from grab samples. Boundary EC is in part based upon hydrology, and

Period	Historical Simulation				January Forecast				March Forecast				May Forecast			
	Barriers			SJR Flow	Barriers			SJR Flow	Barriers			SJR Flow	Barriers			SJR Flow
	OH	GL	MOR	(cfs)	OH	GL	MOR	(cfs)	OH	GL	MOR	(cfs)	OH	GL	MOR	(cfs)
Jan				6,012				2,228				6,012				6,012
Feb				28,091				3,268				28,091				28,091
Mar				19,360				4,586				18,215				19,360
Apr 1-15				22,368				4,655				14,016				21,942
Apr 16-30				21,516	P	R	F	4,655				14,016				21,942
May 1-15				17,055	P	R	F	4,407				9,205				14,637
May 16-31				18,786		P	P	4,407		P	P	9,205				14,637
Jun				17,760		F	F	2,370		F	F	5,143		F	F	7,462
Jul				13,209		F	F	1,822		F	F	4,066		F	F	4,180
Aug				5,445		F	F	2,098		F	F	3,871		F	F	4,359
Sep 1-15				5,467		F	F	2,891		F	F	4,252		F	F	4,924
Sep 16-30				6,044	N	N	N	2,891	N	N	N	4,252	N	N	N	4,924
Oct				6,041	N	N	N	1,789	N	N	N	1,138	N	N	N	1,545
Nov				3,370	N	N	N	1,882	N	N	N	1,344	N	N	N	1,597
Dec				4,187				1,870				1,464				1,708

Barriers Operation Description

Old River at Head (OH)

	No Barrier installed, culverts removed
P	Barrier installed, 6 culverts tied open
N	Barrier installed with 32' notch at 0' msl, culverts tied open

Grant Line Canal (GL)

	No Barrier installed, 6 culverts in and tied open
F	Barrier installed, 6 culverts in and operating
P	Barrier installed, 6 culverts in and tied open
N	Barrier installed with 20' notch at 0' msl, 6 culverts in and operating
R	Barrier not installed, boat ramp in, 6 culverts in and tied open

Old River near Tracy and Middle River (OMR)

	No Barrier installed, culverts in and tied open
F	Barrier installed, culverts in and operating
P	Barrier installed, culverts in and tied open
N	Barrier installed with 20' notch at 0' msl, culverts in and operating

Note: Old River Barrier has 9 culverts while Middle River Barrier has 6 culverts

Table 3. Historical and forecasted installation and operation of temporary barriers for 1998.

because forecasted Delta inflow varied widely from historical, forecasted boundary EC therefore varied from historical. The daily average EC at the downstream boundary Martinez is shown in Figure 7 and summarized in Table 4. Forecasted EC at Martinez was consistently and substantially higher than what historically occurred from June

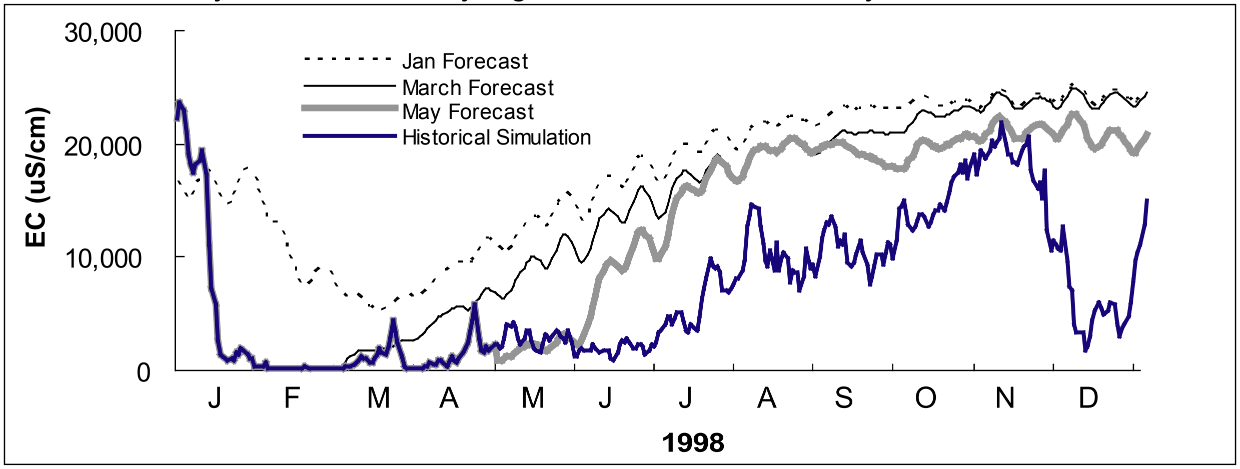

Figure 7. Historical and forecasted daily average EC at Martinez for 1998.

through October and again in December due to under-predicting Delta inflows and outflows.

The forecasted EC in the San Joaquin River at Vernalis was based upon flow-EC relationships developed for this study (Figure 8). While the difficulty predicting EC here only based on the flow at Vernalis is acknowledged, Figure 9 shows that the results are sufficient for the purpose of this study. Future attempts at better forecasts of EC should consider forecasting conditions upstream of Vernalis and modeling water quality in a more rigorous manner. The historical and forecasted EC at Vernalis are shown in Figure 10 and summarized in Table 4. Due to under-predicting San Joaquin River inflows, the forecasts correspondingly significantly over-predicted EC here, without much improvement between the March 1st and May 1st forecasts.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Martinez													
Historical Simulation		9,052	245	1,110	1,482	2,759	1,970	5,999	10,294	10,950	15,517	17,096	5,996
Forecast	January	16,340	10,338	6,245	9,151	13,025	16,503	19,489	21,653	23,006	23,600	23,959	24,244
	March	9,052	245	1,760	5,245	9,293	13,434	16,939	19,317	20,858	22,633	23,708	23,994
	May	9,052	245	1,110	1,482	2,044	8,723	15,793	19,469	19,020	19,938	21,276	20,703
Sacramento River													
Historical Simulation		127	96	124	122	103	106	114	122	128	129	138	121
Forecast	January	150	150	150	150	150	150	150	150	150	150	150	150
	March	150	150	150	150	150	150	150	150	150	150	150	150
	May	150	150	150	150	150	150	150	150	150	150	150	150
Vernalis													
Historical Simulation		477	250	305	204	165	121	152	312	239	261	457	347
Forecast	January	604	494	414	411	423	585	565	523	439	570	660	662
	March	477	250	201	230	287	390	364	374	355	730	787	753
	May	477	250	305	204	225	320	358	350	327	618	720	695

Table 4. Monthly average historical and forecasted boundary EC for 1998 (all values in uS/cm).

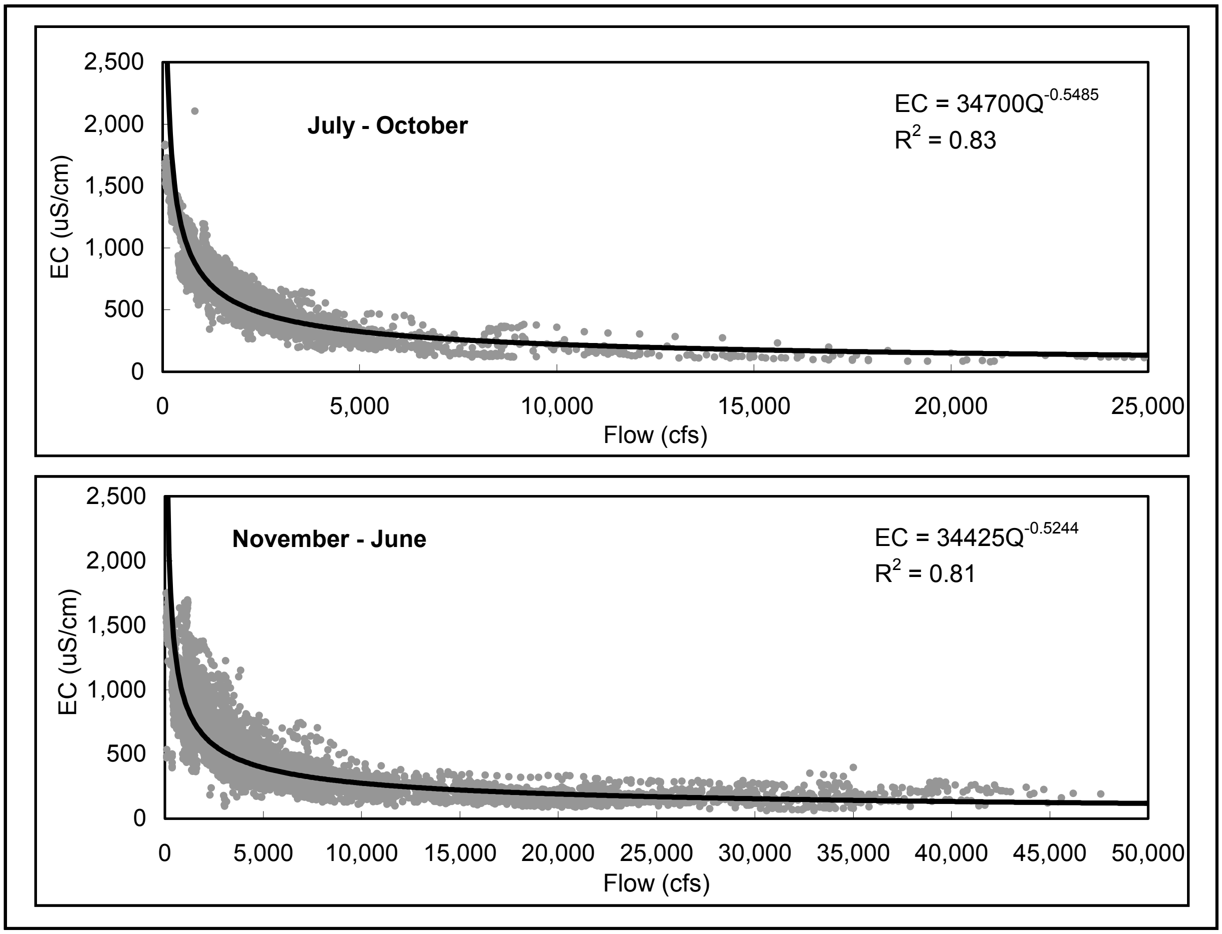

Figure 8. Vernalis Flow-EC relationships.

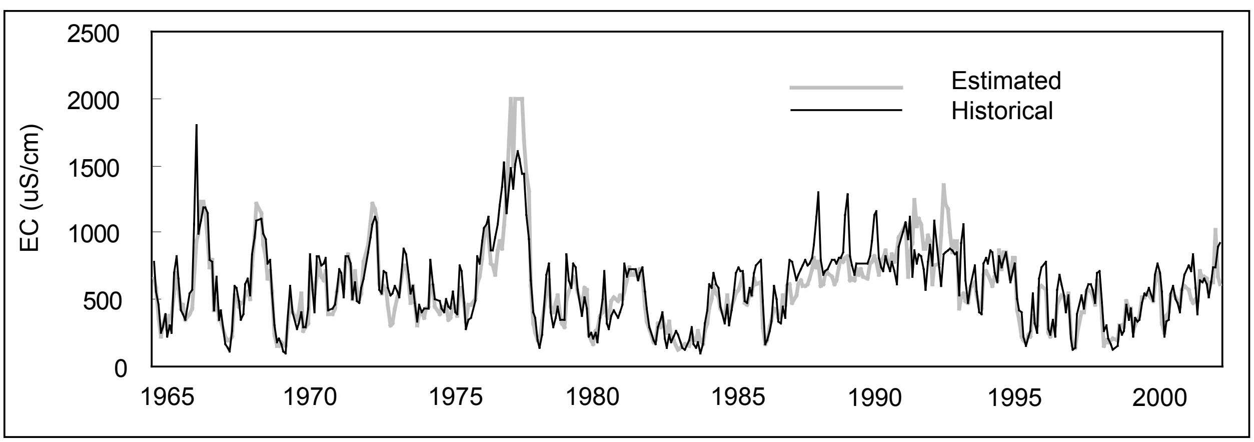

Figure 9. Comparison of historical Vernalis EC to estimated based upon flow-EC relationships

The EC in the Sacramento River was forecasted to be a constant value of 150 uS/cm. This approach is consistent with planning studies and, as Figure 11 and Table 4 show, is not unreasonable, although it too is an overestimation of EC at this boundary.

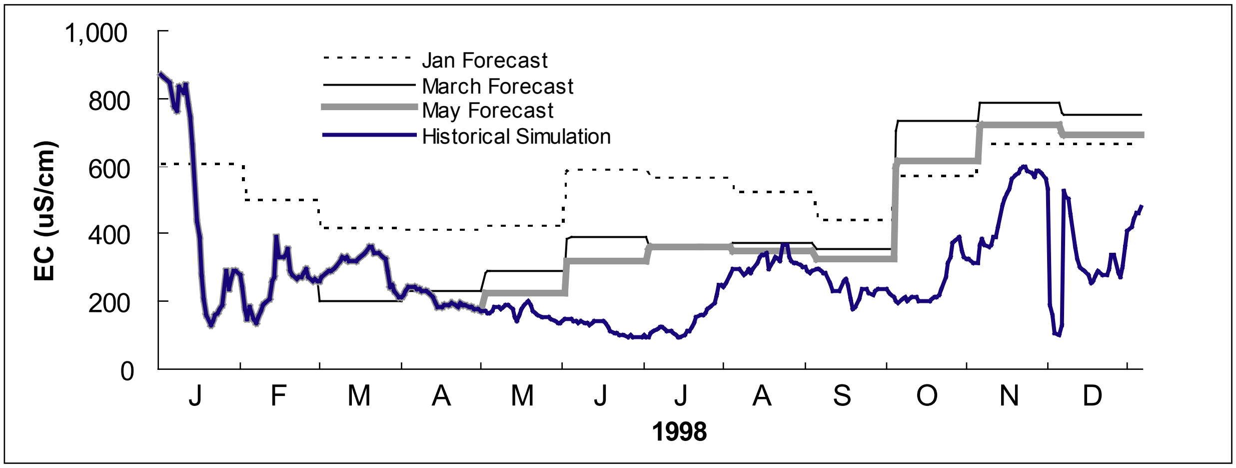

Figure 10. Historical and forecasted San Joaquin River EC for 1998.

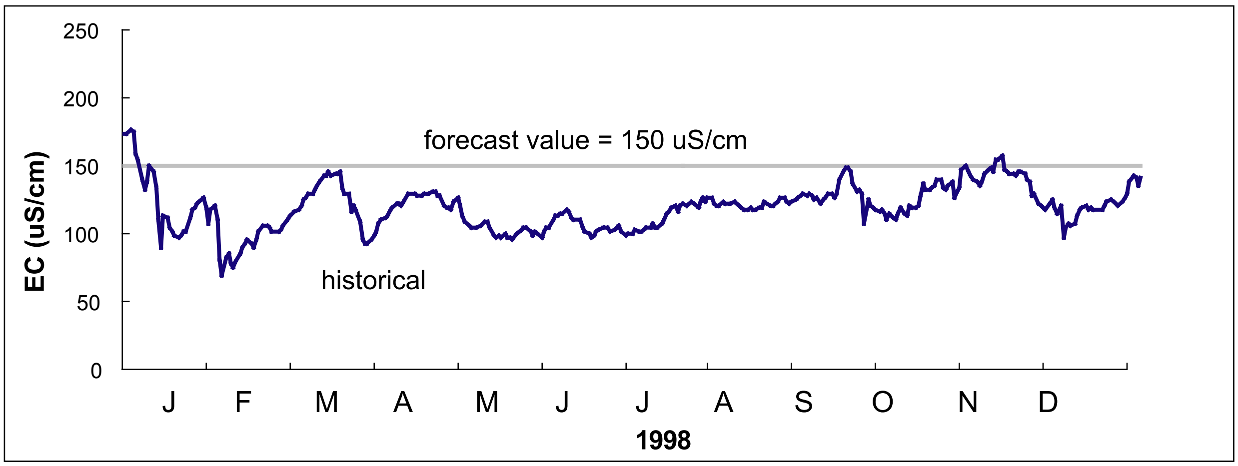

Figure 11. Historical and forecasted Sacramento River EC for 1998.

Water Quality Results

Simulated water quality is reported at the SWP and DMC intakes in terms of EC, TDS, and bromide. As mentioned before, DSM2 only simulated the transport of EC. Daily average EC was then converted to TDS and bromide according to the equations from the relationships shown in Figures 12 and 13. Water quality results of the historical simulation and the three forecasts for 1998 at the SWP and DMC intakes are shown in Figures 14 and 15 respectively, and are summarized in Table 5. The January 1st and March 1st forecasts substantially over-predicted EC at the SWP and DMC intakes. However, significant improvement at both locations is seen in the May 1st forecast compared to the earlier forecasts.

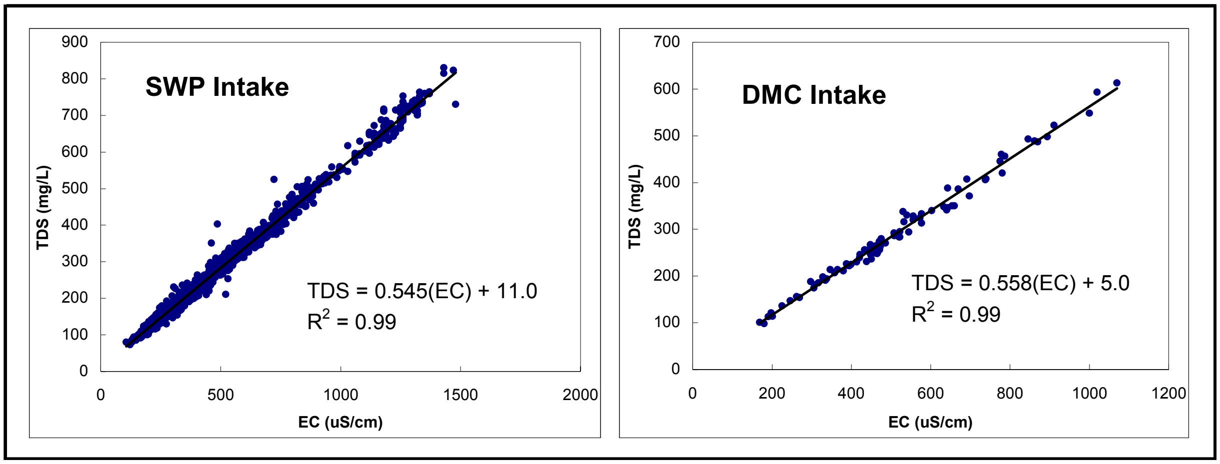

Figure 12. Relationships between TDS and EC at SWP and DMC intakes.

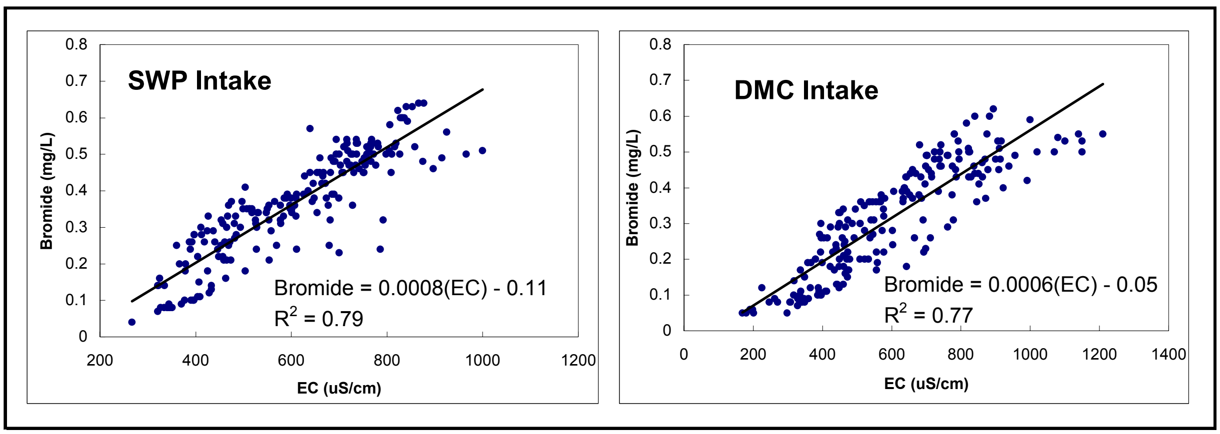

Figure 13. Relationships between Bromide and EC at SWP and DMC intakes.

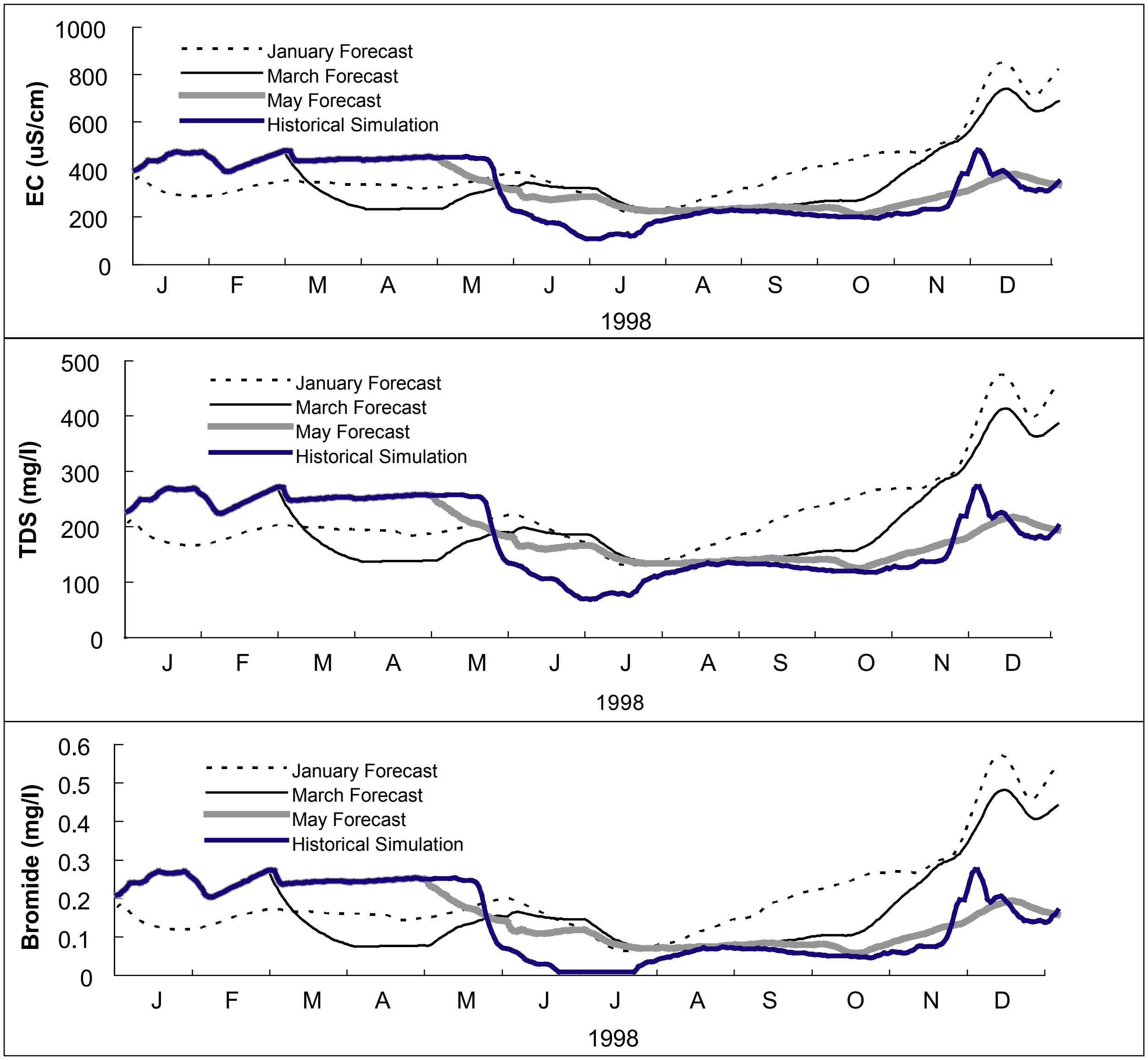

Figure 14. Simulated historical and forecasted EC, TDS, and bromide at SWP intake for 1998.

Discussion

The pattern of decreasing forecasted EC at the SWP intake in the fall of 1998 as the forecasts moved from January to May is consistent with model results downstream of the SWP intake. As Figure 16 indicates, the modeled historical EC at Antioch and Jersey Point was significantly less that forecasted EC. The May 1st forecast showed a more than 50% decrease in EC from the March 1st forecast, but still exceeded the EC from the historical run. At Old River at Rock Slough, the pattern of historical and forecasted modeled EC is similar to that seen at the SWP intake. Trends as shown in Figure 16 indicate that the higher Delta outflows in March and April before the May 1st forecast reduced the amount of salinity in the west Delta, thus preventing the higher salinity from moving inland and down the towards the SWP intake. Figure 17

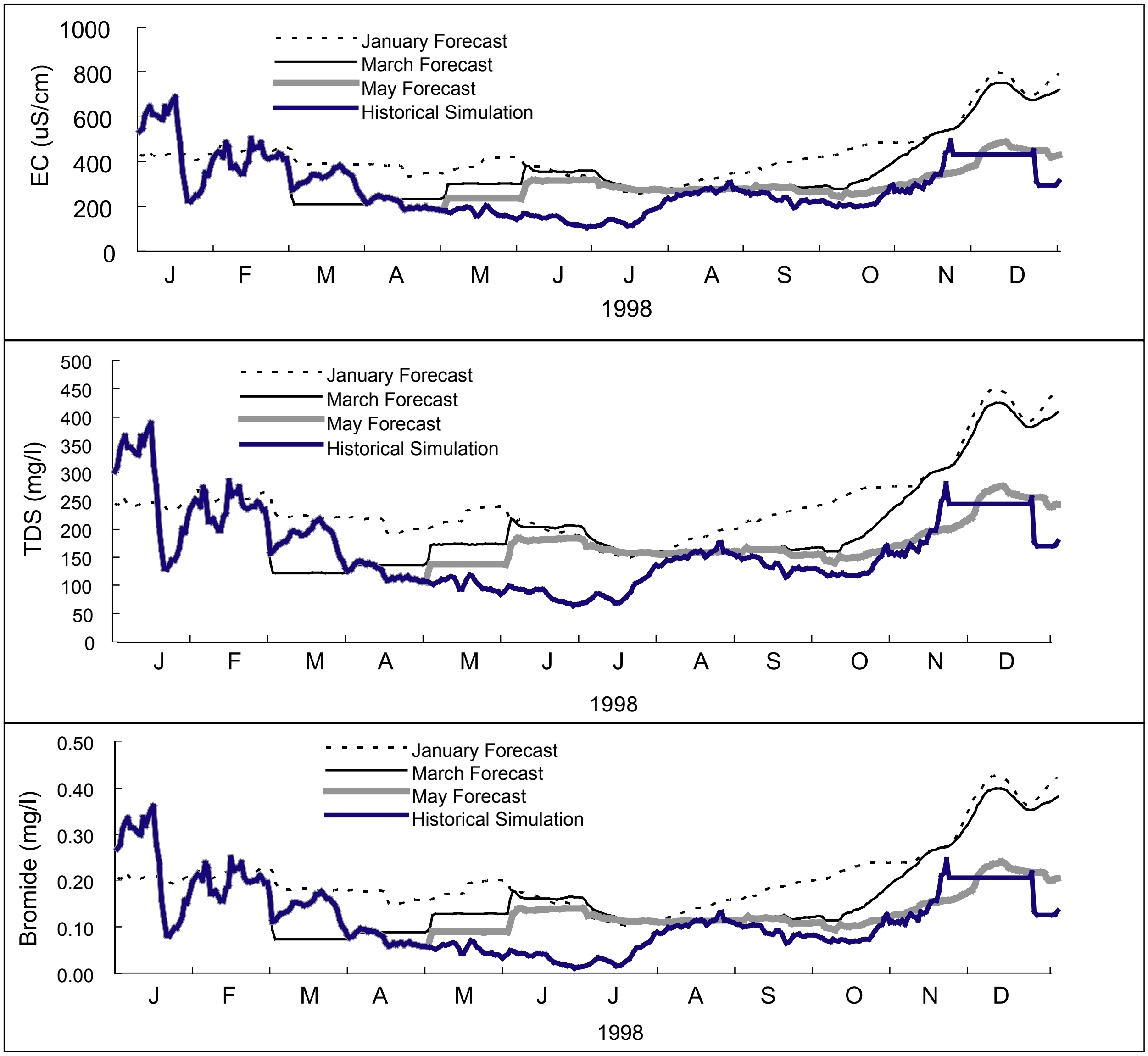

Figure 15. Simulated historical and forecasted EC, TDS, and bromide at DMC intake for 1998.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SWP Intake													
EC (uS/cm)													
Historical Simulation		452	430	445	447	396	166	143	218	217	203	296	353
Forecast	January	310	323	345	329	355	339	236	283	378	453	534	783
	March	452	430	320	234	295	329	256	230	250	300	495	687
	May	452	430	445	447	365	282	242	231	240	229	290	359
TDS (mg/l)													
Historical Simulation		257	245	253	255	227	102	89	130	129	122	172	204
Forecast	January	180	187	199	191	205	196	140	165	217	258	302	438
	March	257	245	186	138	172	190	151	136	147	174	281	386
	May	257	245	253	255	210	165	143	137	142	136	169	207
Bromide (mg/l)													
Historical Simulation		0.25	0.23	0.25	0.25	0.21	0.03	0.02	0.06	0.06	0.05	0.13	0.17
Forecast	January	0.14	0.15	0.17	0.15	0.17	0.16	0.08	0.12	0.19	0.25	0.32	0.52
	March	0.25	0.23	0.15	0.08	0.13	0.15	0.09	0.07	0.09	0.13	0.29	0.44
	May	0.25	0.23	0.25	0.25	0.18	0.12	0.08	0.08	0.08	0.07	0.12	0.18
DMC Intake													
EC (uS/cm)													
Historical Simulation		470	422	323	211	174	139	157	268	232	228	373	389
Forecast	January	428	449	394	363	392	356	275	325	398	467	561	752
	March	470	422	215	234	298	357	291	275	288	336	543	714
	May	470	422	323	211	234	312	281	275	277	268	348	457
TDS (mg/l)													
Historical Simulation		267	241	185	123	102	82	93	155	134	132	213	222
Forecast	January	244	255	225	208	224	204	159	186	227	266	318	425
	March	267	241	125	136	171	204	167	158	166	193	308	403
	May	267	241	185	123	136	179	162	159	160	155	199	260
Bromide (mg/l)													
Historical Simulation		0.23	0.20	0.14	0.07	0.05	0.03	0.04	0.11	0.09	0.09	0.17	0.18
Forecast	January	0.21	0.22	0.18	0.17	0.18	0.16	0.11	0.14	0.19	0.23	0.28	0.40
	March	0.23	0.20	0.08	0.09	0.13	0.16	0.12	0.11	0.12	0.15	0.27	0.38
	May	0.23	0.20	0.14	0.07	0.09	0.14	0.12	0.11	0.11	0.11	0.16	0.22

Table 5. Summary of simulated historical and forecasted water quality at SWP and DMC intakes for 1998 (all values in uS/cm).

shows this trend directly as the modeled EC at the SWP intake is broken down by the contribution of four sources: the west Delta at Martinez, the Sacramento River, the San Joaquin River, and agricultural drainage. In the historical run, which consisted of high Delta inflows, virtually none of the water from the west Delta reached the SWP intake. In contrast, the January 1st and March 1st forecasts resulted in higher total EC at the SWP intake, with the water at Martinez significantly contributing. Again, as the forecasted Delta inflows increased from the January 1st forecast to the May 1st forecast, the west Delta contributed less water and associated EC to the EC reported at the SWP intake.

Examination of the information presented here, namely Delta inflows, exports, Delta Cross Channel operation, timing of the installation and operation of south Delta temporary barriers, and modeled EC by components, together indicate that the

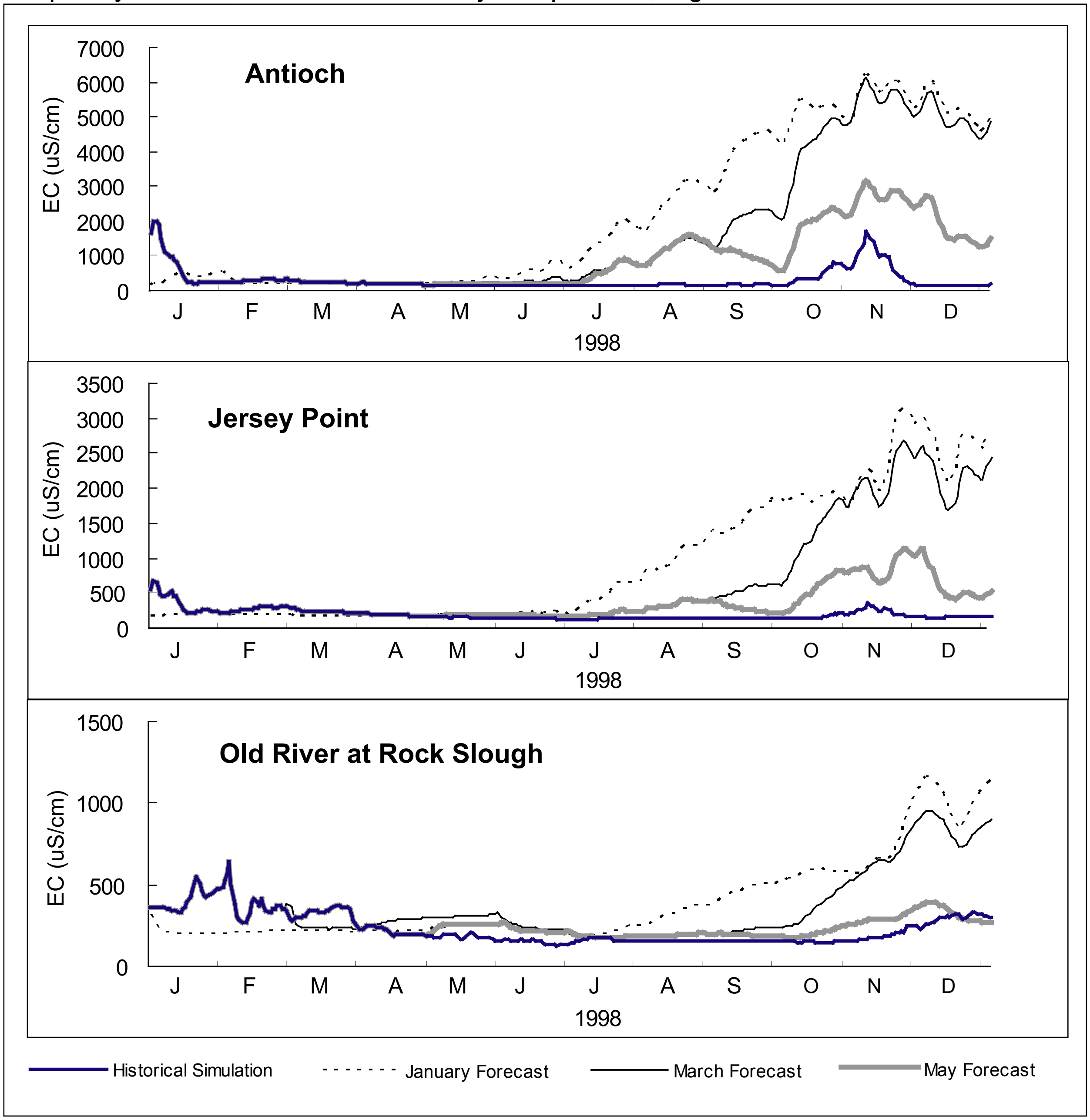

Figure 16. Simulated 1998 historical and forecasted EC downstream of the SWP intake.

significantly improved forecasted EC by the May 1st forecast is due to a combination of factors, rather than simply a more accurately forecasted Delta inflows and exports. The May 1st forecast included higher Delta inflows which results in significantly lower EC in the west Delta when compared to the March 1st forecast (Figure 16). However, the May 1st forecast (as well as the January 1st and March 1st forecasts) left the Delta Cross Channel open to mid-November and opened it again for the first half of December when the historical operation was closed. In addition, the three forecasts operated the temporary agricultural barriers through November as well as the fall barrier at the head of Old River in October and November. As a result, the forecasted October - December EC at the SWP intake originated from Martinez, the Sacramento River, the San Joaquin River, and agricultural drainage, while the historical simulation indicates that the EC actually mostly came from the San Joaquin River during the same period (Figure 17).

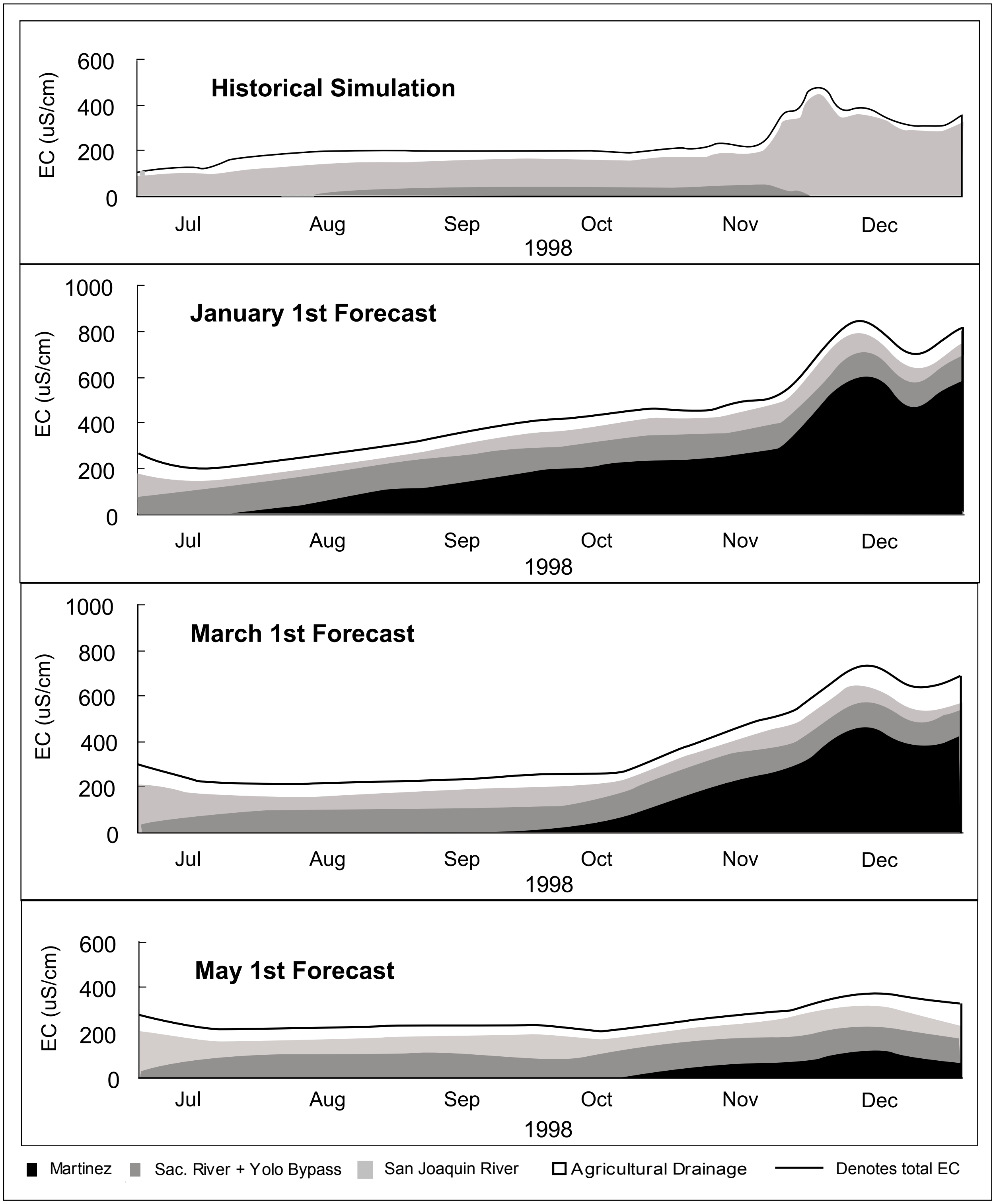

Figure 17. Simulated 1998 historical and forecasted EC at SWP intake by contributing component.